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28th April 2022

DEVELOPMENT AND DEMONSTRATION OF AUTONOMOUS SHIP IN JAPAN

28th April 2022

NYK Approach for Design, Development and Demonstration of Fully Autonomous Navigation Ship

Hideyuki Ando [1)]
Capt. Satoru Kuwahara [2)]
Capt. Koji Kutsuna [1)]
Capt. Jun Nakamura [1)]

1) MTI (NYK Group)
2) Japan Marine Science (NYK Group)

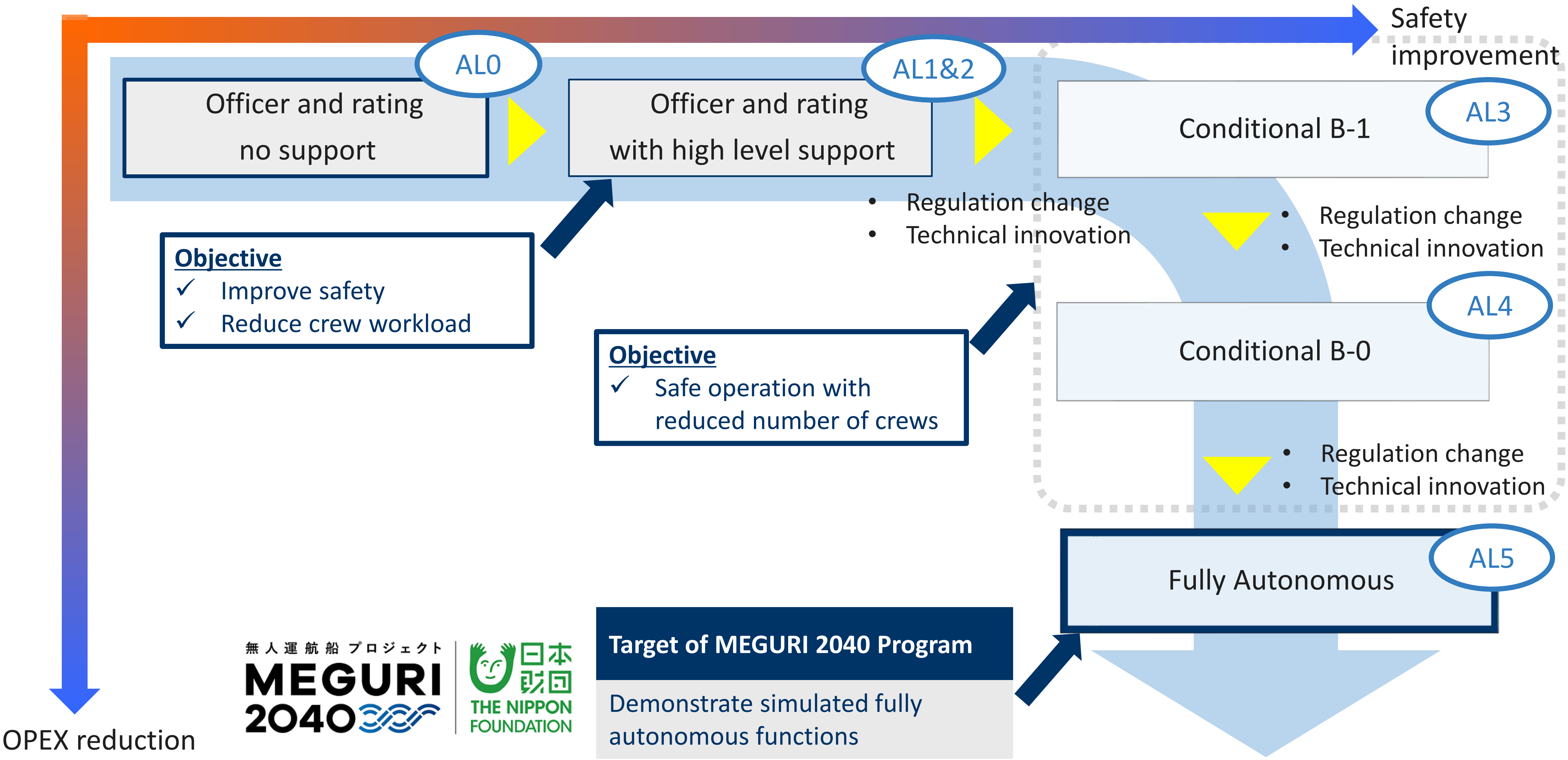
“Challenge to Realize Fully Autonomous Ship” (Short version) — DFFAS Consortium Documentary on YouTube:

https://www.youtube.com/watch?v=oWy0l15OzmA

Outline

1. **Introduction of DFFAS Project**
2. System overview
3. System design and development process
4. Demonstration
5. Summary

Our view of Autonomous Ship roadmap and MEGURI2040 program



* AL0 – 5 refers autonomy level (AL) definition by Lloyd’s Register, Cyber-enabled ship, 2016

Ambition of DFFAS Project in MEGURI 2040 Program

Challenge

- To solve labor shortage in the domestic shipping industry, which has supported Japanese domestic logistics with social implementation of fully autonomous ship technology

Goal

- Developing technologies that will lead to the future through Open Innovation, with a view to long-term industrial growth, and envisioning a Grand Design for autonomous ship in Japan and around the world.

DFFAS Project (Designing the Future of Full Autonomous Ship)

Designing the Future of Full Autonomous Ship

Target

- Demonstrate fully autonomous ship navigation functions under MEGURI 2040 program in Mar 2022

DFFAS consortium members & partners

- Consortium: 30 organizations (domestic)
- Total: 60+ organizations (including global partners)

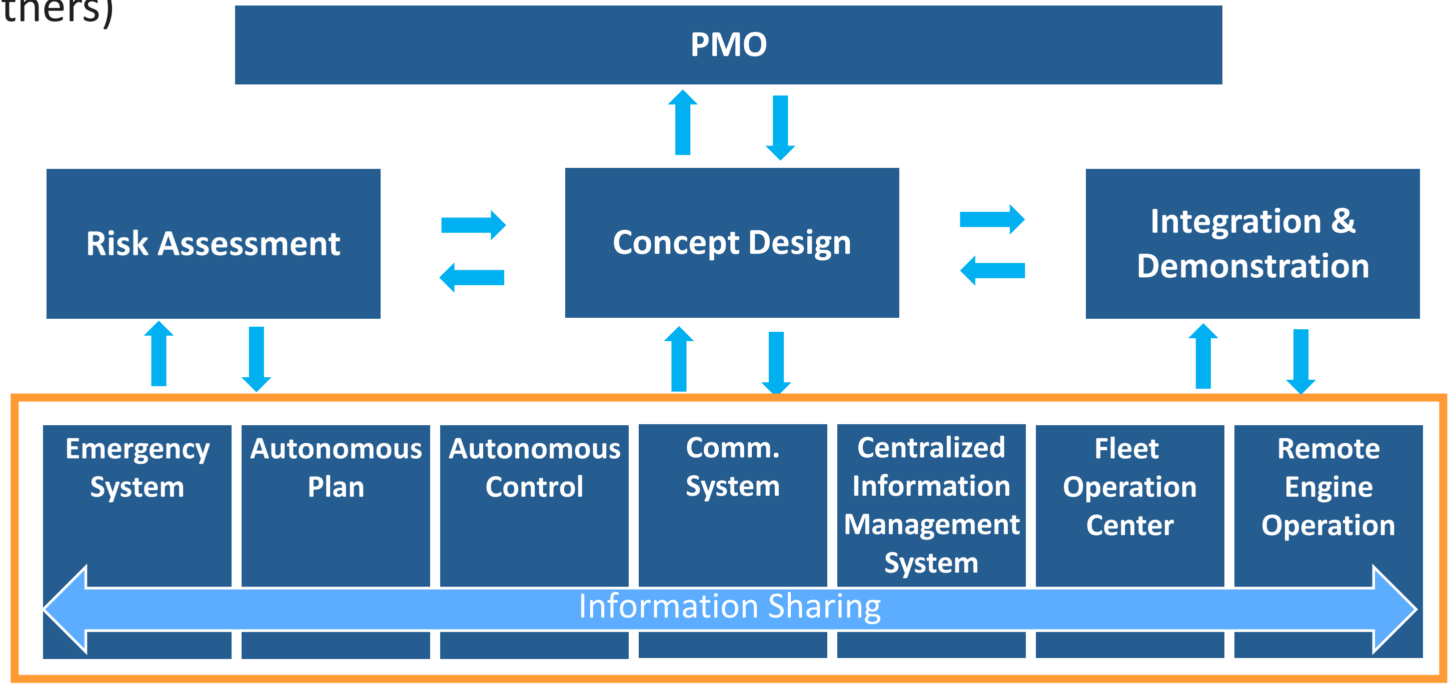
Schedule

- Feb 2020 – Mar 2022 (abt. 2 years)

Target ship and route	Container ship "Suzaku", 749GT Tokyo bay – Ise bay

Project Director
Capt. Satoru Kuwahara

Organization of DFFAS Project



Background target: Develop open architecture & open process for autonomous ship design, development, construct, commission and operation for to realize social implementation of autonomous ships for all AL levels.

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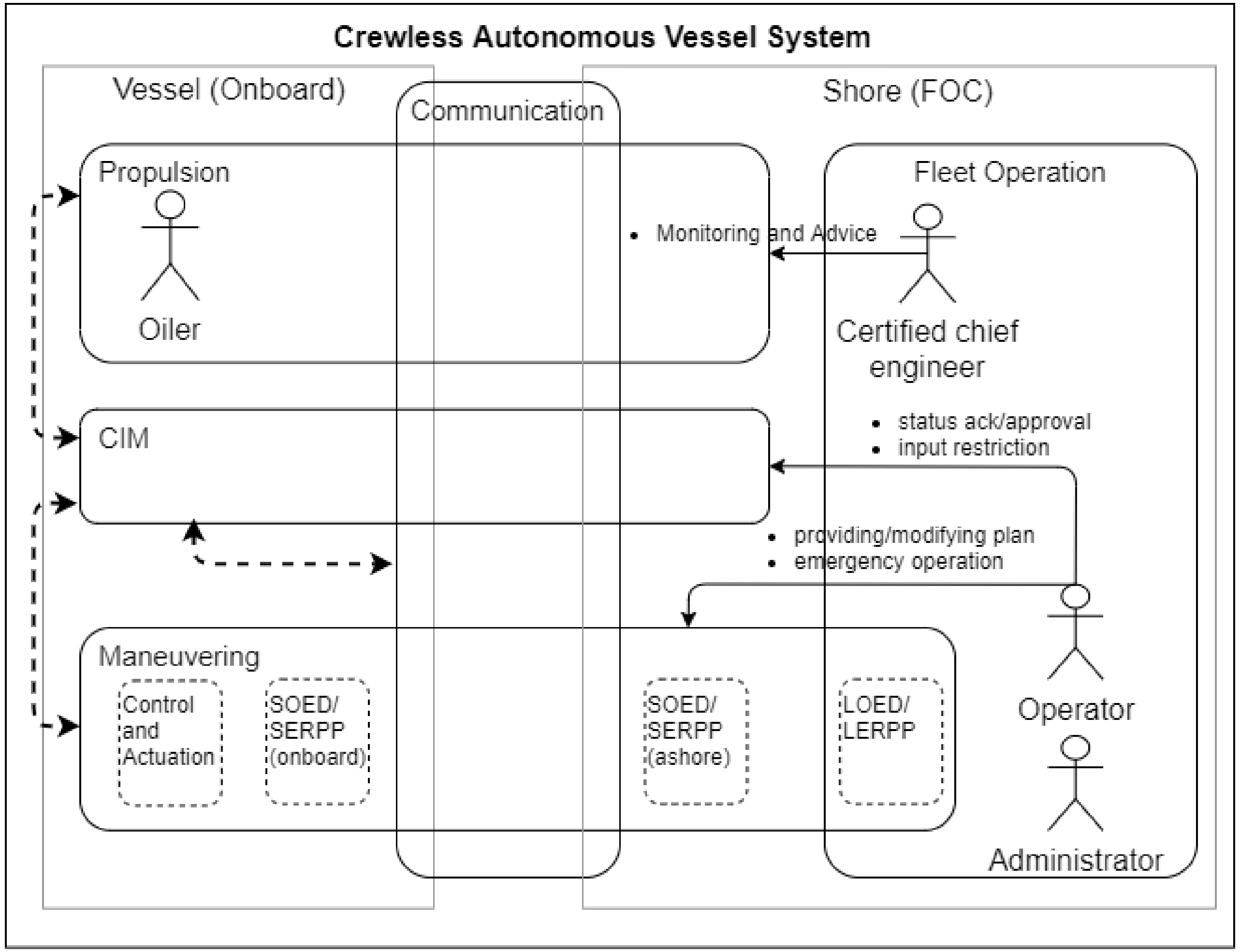
Definition of system requirements with deep domain knowledge

To formulate the conceptual design of an autonomous navigation system, two deep knowledge domains, the master mariners' and chief engineers' knowledge of the operational domain and the manufacturers' knowledge of the technical domain, are essential,

- Master mariners and chief engineers, who are well versed in ship operations, lead the project, define the concept of operations (ConOps), design autonomous ship navigation system and iterate risk assessment, for eliciting system requirements together with engineers of manufactures and system specialists by using Model-Based Systems Engineering (MBSE) approach.



High level concept description by using use case diagram

DFFAS System Composition and System Status Definition

DFFAS System Composition

- Maneuvering
- Propulsion
- Communication
- Centralized Information Management system (CIM)
- Fleet Operation Center system (FOC)

System status definition

The definition of the whole system status is based on degree of engagement by human on shore and necessity of fallback operation.

Normal:	System is running without any intervention by crew or fallback from shore.
Active Monitoring (AM):	System is running under the verification by operator at shore.
Remote Fallback (RFB):	System is running under fallback operations by operator at shore.
Independent Fallback (IFB):	System is running under fallback operations by system on vessel.

Task category, Executor and Location

Table 3.1: Task category, executor and location

Task		Executor	Location
Situation awareness (Detection)	Long Term Object & Event Detection (LOED)	Machine, Human	Shore
	Short Term Object & Event Detection (SOED)	Machine	On board
Decision making (Integration/Analysis/Planning)	L-Event Response & Path Planning (LERPP)	Machine Human (including/restriction, approval)	Shore
	S-Event Response & Path Planning	Machine	On board Shore (status: AM/RFB)
	(SERPP)	Human	Shore (status: AM/RFB)
	CIM	Machine	On board
		Human (operation for system status)	Shore
Execution (Control/Actuation)	DTC and propulsion	Machine	On board
(Independent) Fallback		Machine	On board

CIM: Centralized Information Management
DTC: Drive Train Controller

Ref) MTI, APExS-auto system overview, DFFAS PJ, MARCH 2022

DFFAS system overview

Telecommunication system
(3 satellite and 1 terestrial communication lines, information management & control)

DFFAS

DFFAS

Onboard system
(autonomous functions)

MEGURI 2040

DFFAS

Integrated Display Block
(ship information collection, monitoring & analysis)
(engine remote monitoring, control & anomality detection)

Emergency Response Block
(remote operation function)

Land-based system
(land-based support functions)

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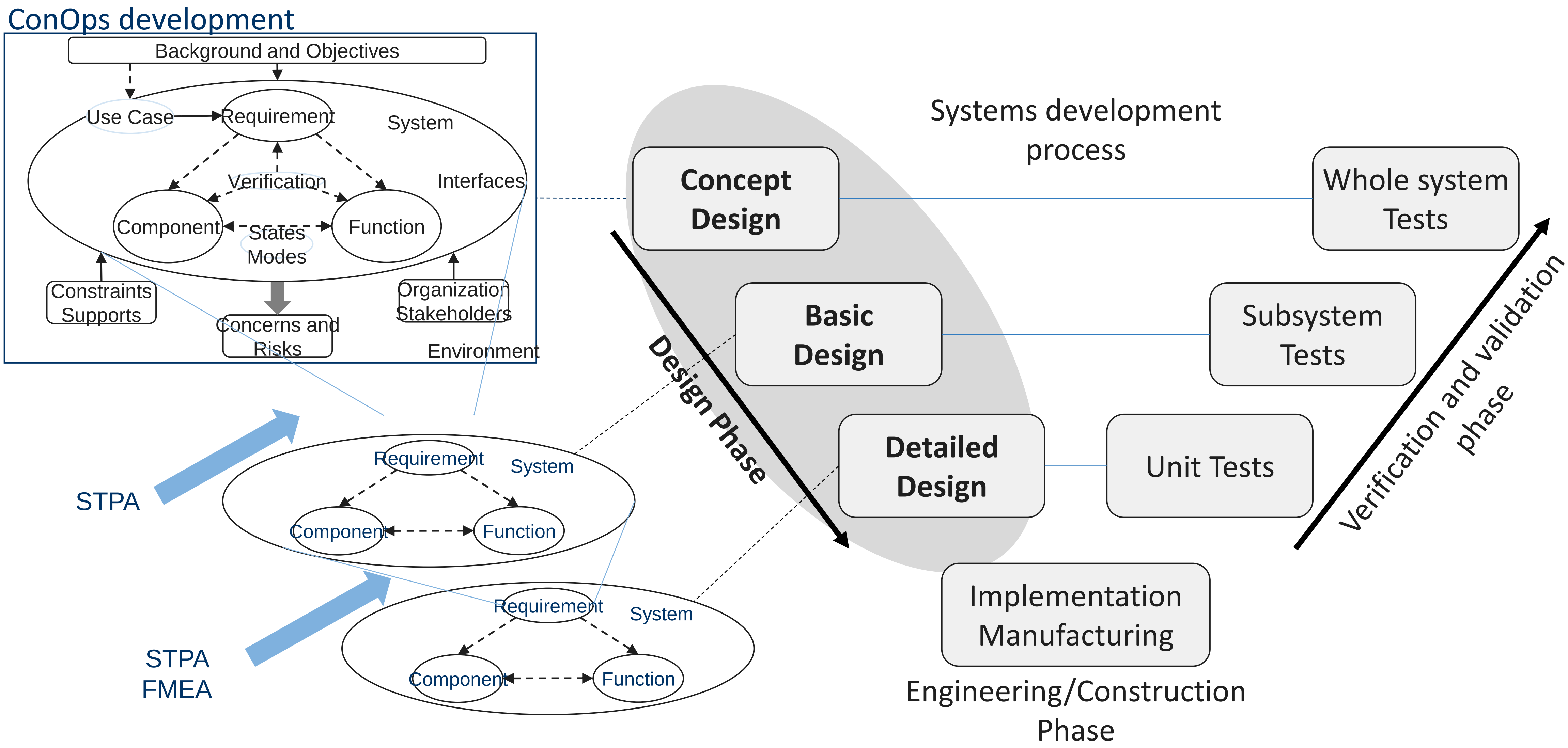
Methodology - V Process



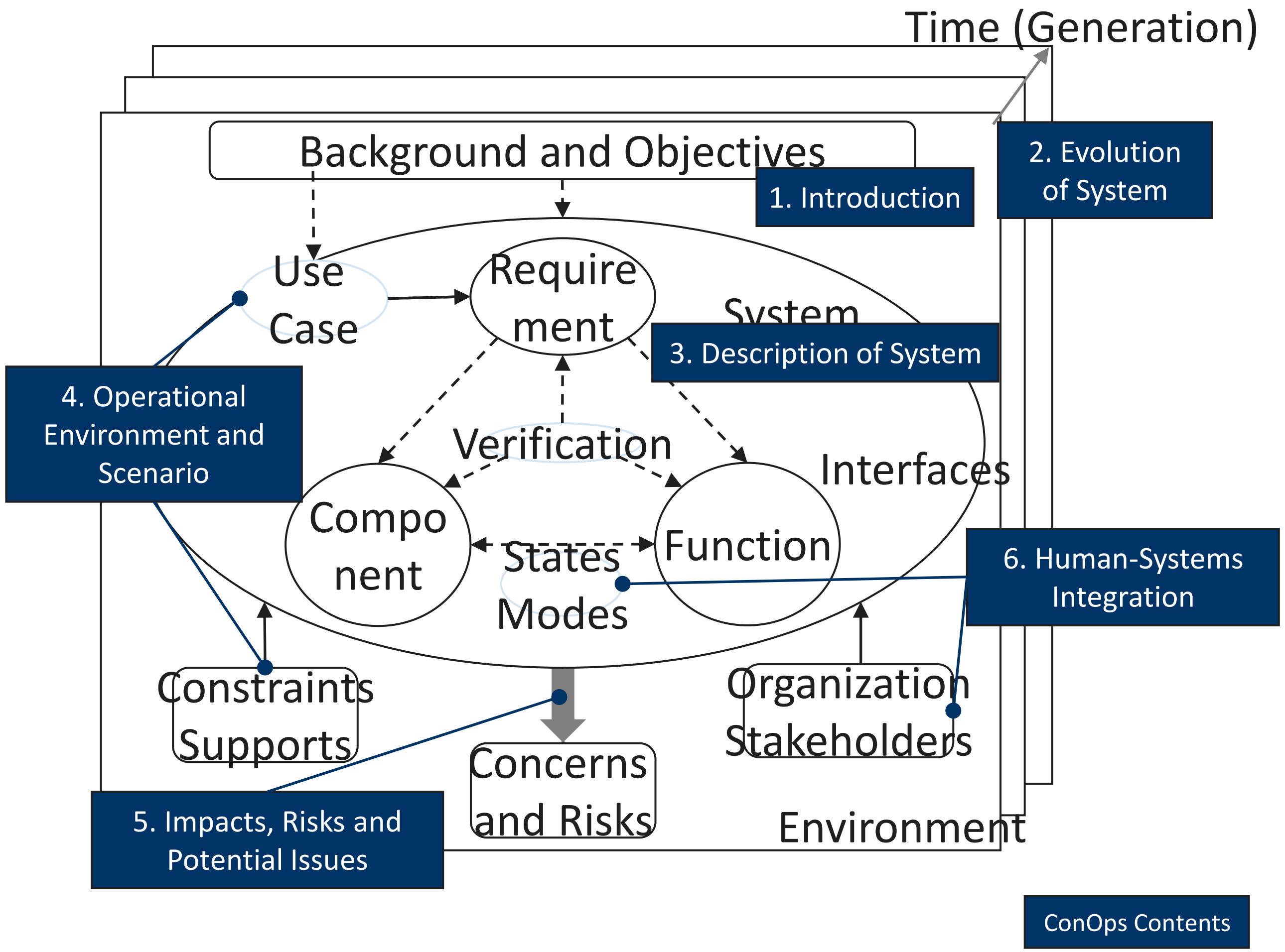
* STPA (Systems Theoretic Process Analysis)
* FMEA (Failure Mode and Effects Analysis)

Concept of Operation (ConOps)

ConOps contents for autonomous system

Contents	Description
1. Introduction	• Background • System Scope, Assumption & Constraints
2. Evolution of System	• Justification for changes • Future Roadmap and Status of the envisioned system
3. Description of System	• Needs, Goals & Objectives of the system • Overview Architecture incl. Interfaces (Major System elements & interconnections) • Modes of Operation • Basic Functions (Proposed Capabilities)
4. Operational Environment and Scenario	• Use Cases (Nominal, Off nominal) • Actors/Stakeholders • Operational Scenario • Data flow (input & output of the system)
5. Impacts and Potential Issues	• Operational impacts, Environmental Impacts, Organizational Impacts, Scientific/Technical Impacts • Regulatory Compliance, How to Implement the system
6. Human-Systems Integration	• Human-in-the-loop involvement • Human-machine interface etc.
Appendix	• Glossary, Acronyms, Reference Documents

Required elements for system description



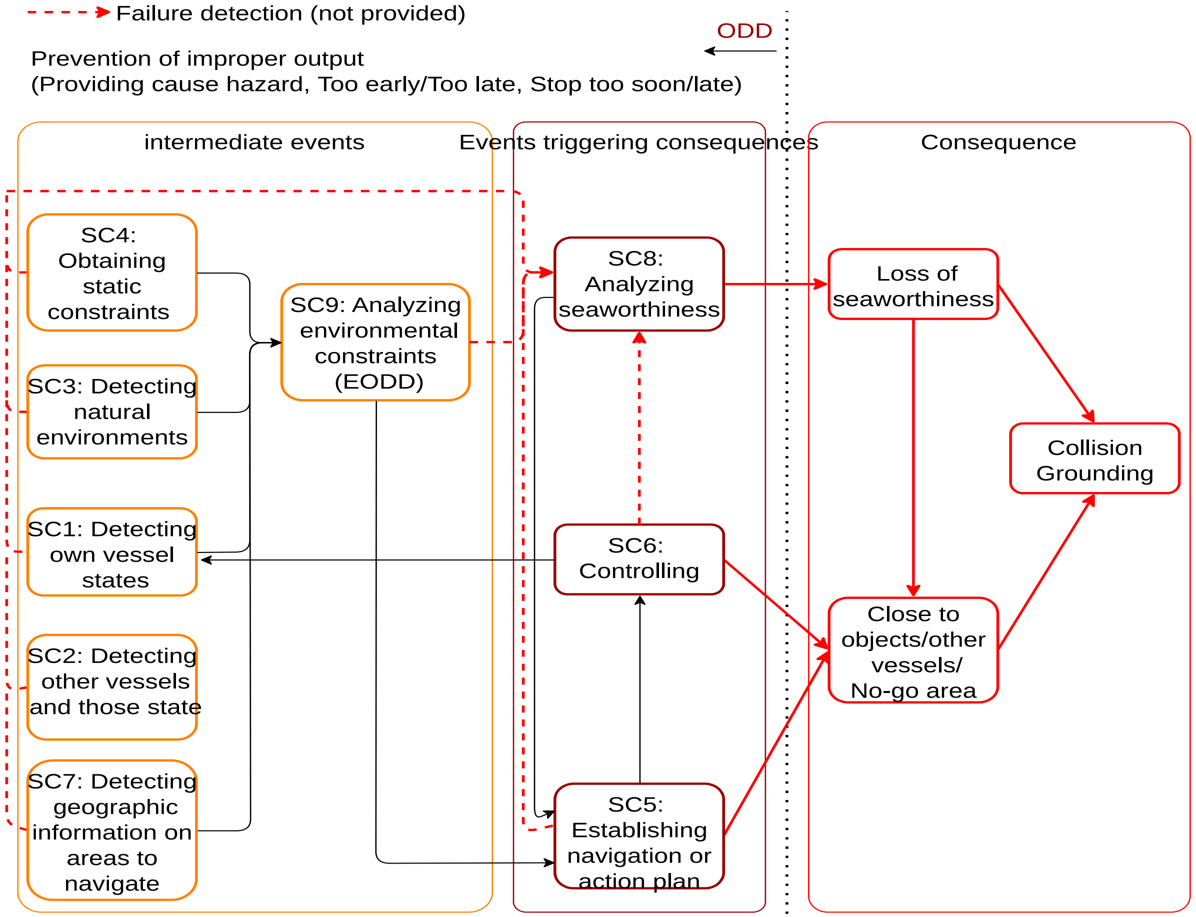
Ref. INCOSE Systems Engineering Handbook

Safety Constraints (SC)

- Violations of Safety constraints (SC) are defined as hazardous events, which should be avoided.
- SCs can be considered as the sub-goals to achieve the goal, safety autonomous navigation.
- Unsafe control actions were extracted by using STPA analysis and Bow-Tie risk assessments were used to define system requirements.

SC	Description
SC1	Own vessel states must be detected: system conditions and sensor-detected values etc.
SC2	Other vessels and those states must be detected: existence and course, heading, speed and positions.
SC3	Natural environments which affect the system must be detected: wind, wave, tidal stream, temperature, etc.
SC4	Static constraints which are essential to achieve voyage must be obtained.
SC5	Navigation and/or action plan must be established.
SC6	Control signal must be calculated based on navigation/action plan.
SC7	Geographic information to navigate must be detected.
SC8	Seaworthiness including condition of equipment and hull must be analysed and actions must be selected based on own status and surrounding environment.
SC9	Dynamic constraints must be analysed based on static constraints and internal/external environment (e.g., short stopping distance, Turning circle).

Safety Constraints

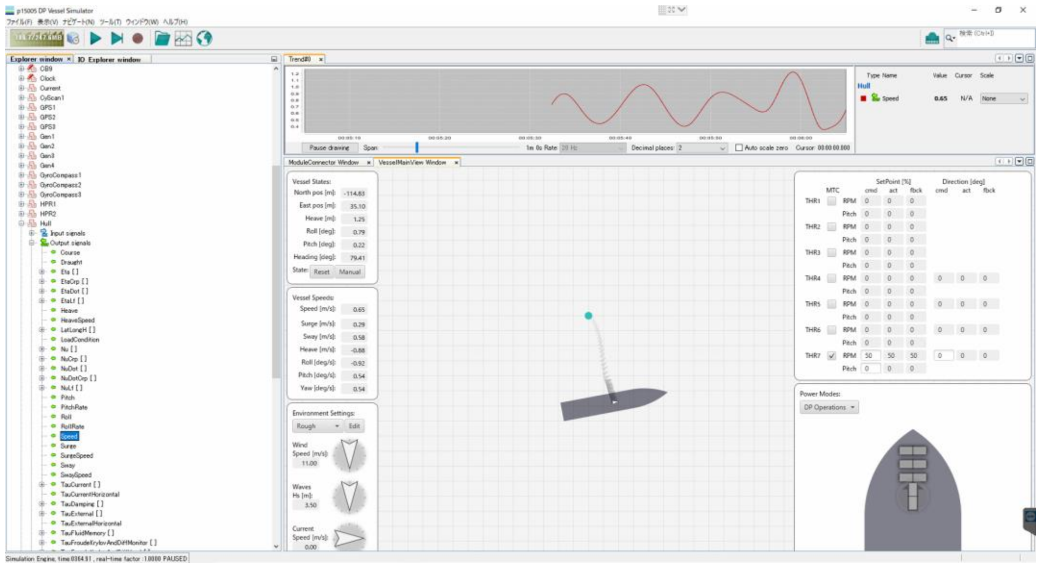


The autonomous system concept design, APExS-auto, received AiP from ClassNK and BV in March 2022

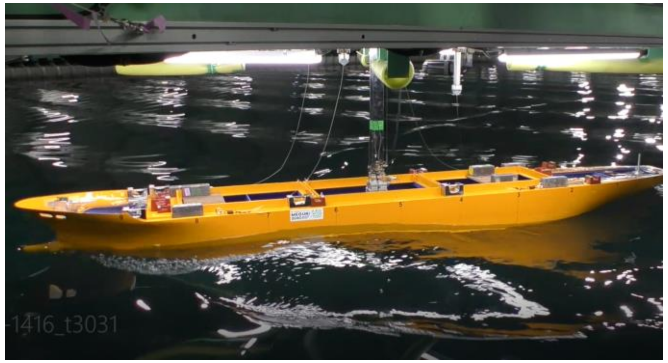
Simulation tests for to prevent potential failures of control systems

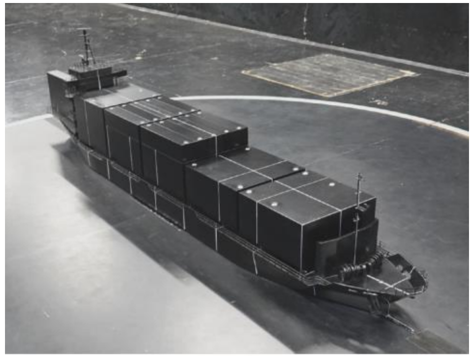
- Simulation tests are utilized for unit test and system integration test.
  - MIL(Model-In-the-loop)
  - HIL(Hardware-In-the-loop)
- As the base of simulation test, simulation platform CyberSea(DNV) is used.
- Vessel dynamic models built as FMU*. FMU parameters of hull, thruster & rudder are calibrated based on model test results and actual ship data at sea trials.

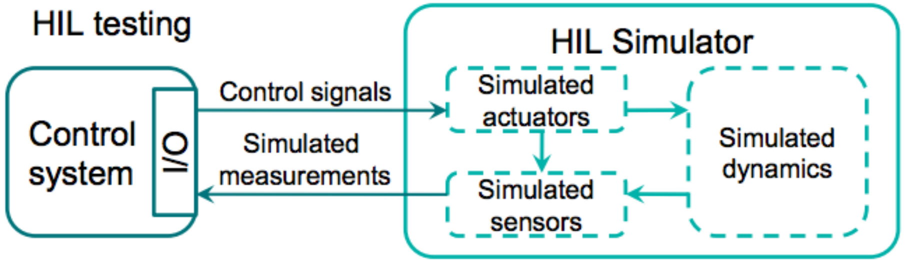
* FMU (Function Mockup Unit)



Simulation test platform CyberSea (DNV)







Ref) DNV Marine Cybernetics Advisory
https://www.dnvgl.com/services/hil-testing-concept-explanation--83385

System integration test @ FOC (Jun – Aug 2021)

- System integration tests were conducted to identify issues before actual installation of the system on the target vessel

- All the system/equipment except for some sensors (e.g. radar) are integrated and tested with a virtual ship on CyberSea simulator.

- Normal/abnormal situations are tested for coastal navigation, berthing and unberthing scenario
  - Normal … 75 sequence
  - Abnormal … 34 sequence
  - Through voyage … 8 voyages

Snapshot of system integration test
@ Fleet Operation Center (FOC)

→ 30 items undetected by STPA, FMEA, and unit and coupling tests were corrected prior to loading the system on the vessel.

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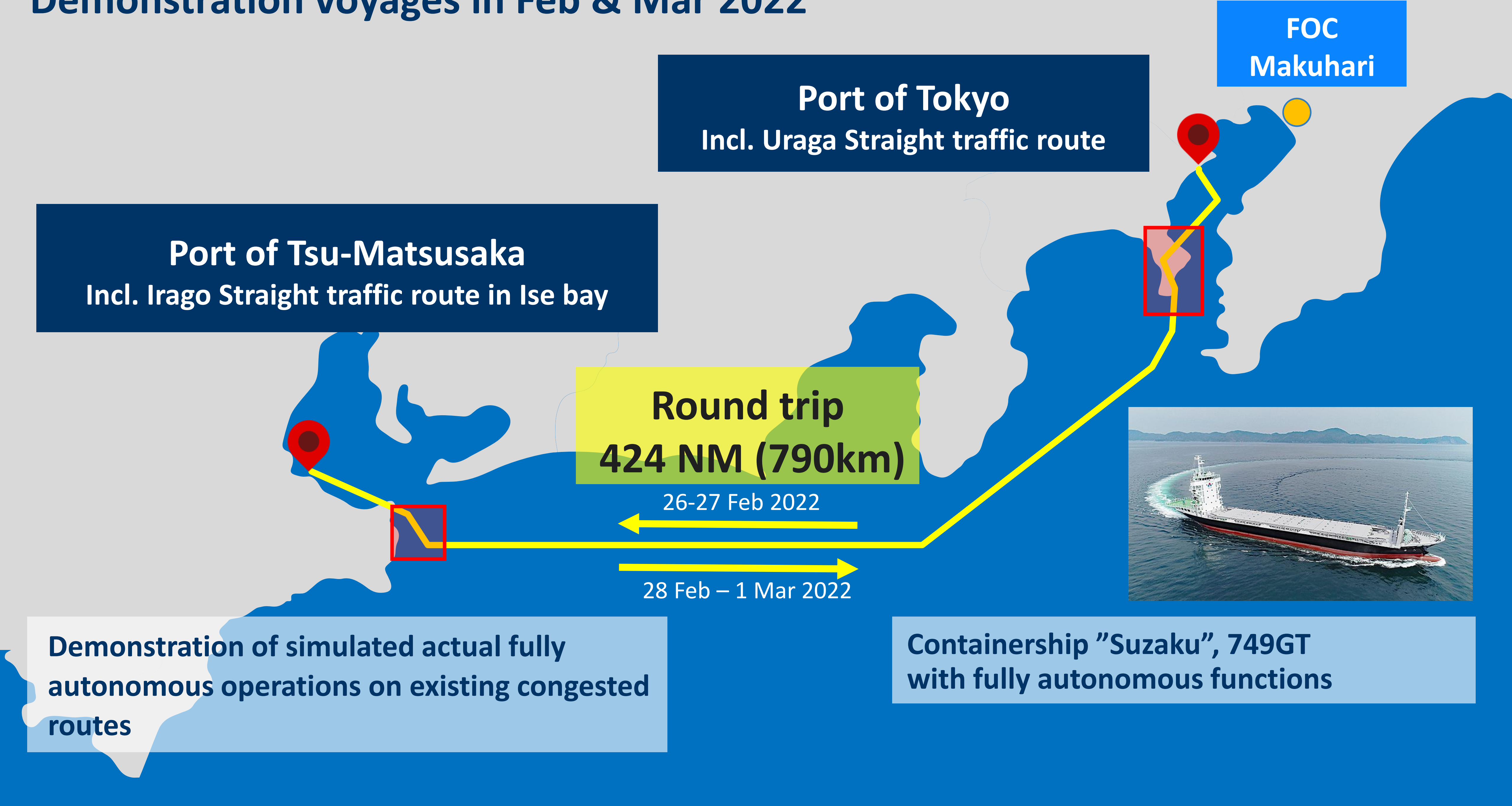
Demonstration voyages in Feb & Mar 2022



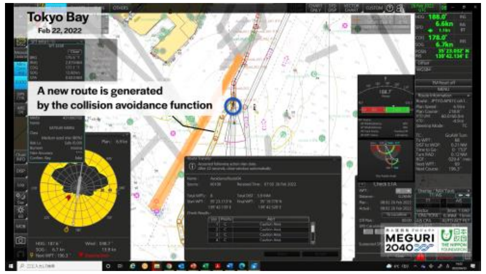
Demonstration of simulated actual fully autonomous operations on existing congested routes

Containership "Suzaku", 749GT with fully autonomous functions

An example case of collision avoidance in Tokyo bay on 26 Feb 2022

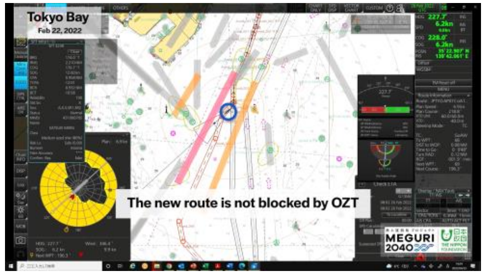
7:59:16 AM

- The planned route is blocked by Obstacle Zone of Target (OZT) of other surrounding ships.



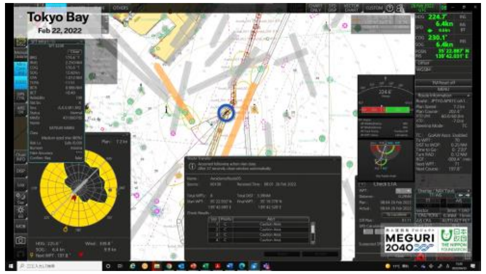
8:00:04 AM

- A new route is generated by the collision avoidance function
- The new route is automatically approved by the system under supervision by shore captain.



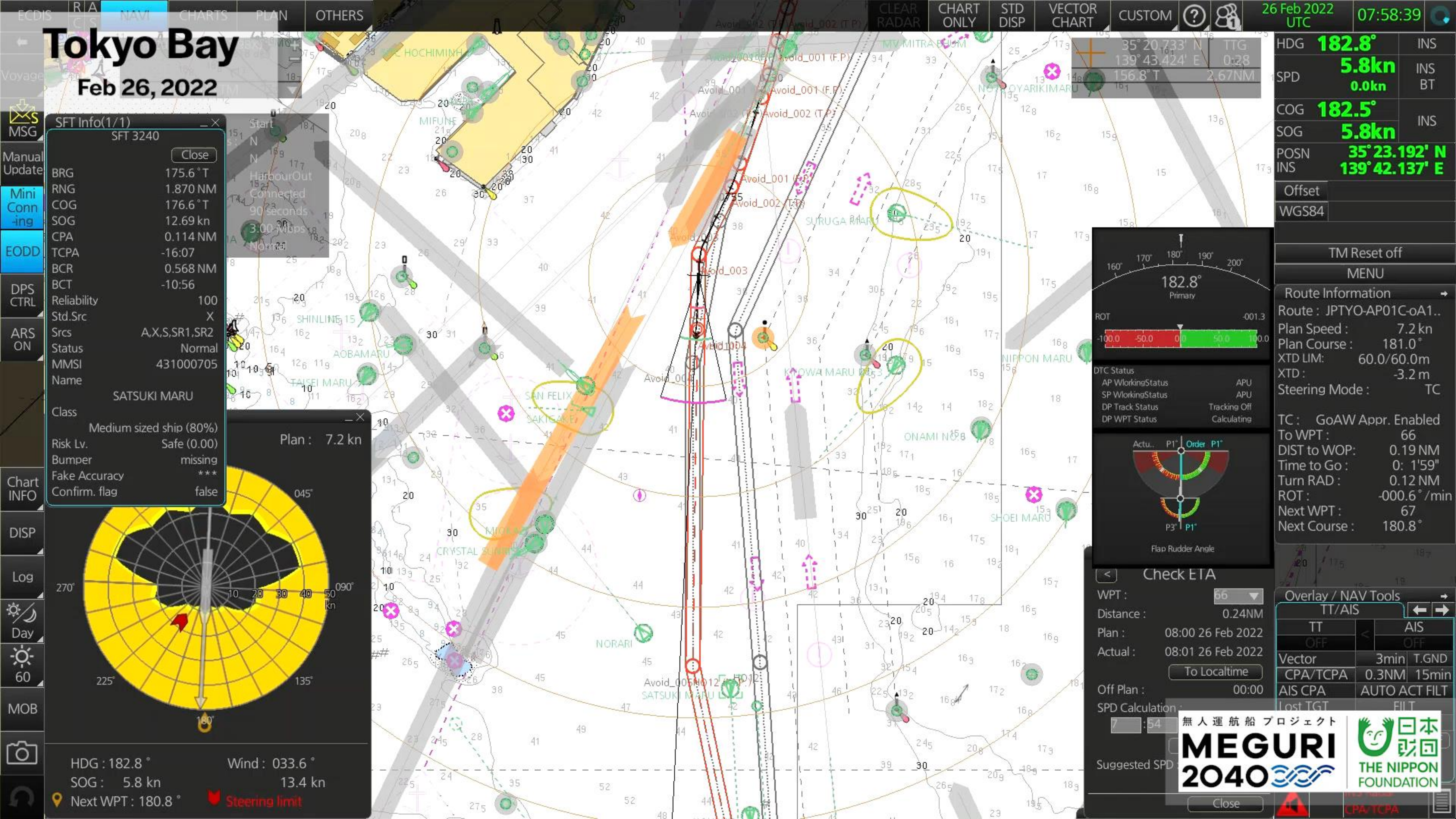
8:01:09 AM

- The new route is not blocked by OZTs and the vessel automatically track the new route.



8:01:53 AM

- The collision avoidance function generates a slightly modified new route due to occurrence of another OZT
- The new route is automatically approved by the system under supervision by shore captain.



Tokyo Bay
Feb 26, 2022
ECDIS
NAVI
CHARTS
PLAN
OTHERS
CLEAR RADAR
CHART ONLY
STD DISP
VECTOR CHART
CUSTOM
26 Feb 2022 UTC
07:58:39
HDG 182.8° INS
SPD 5.8kn 0.0kn INS BT
COG 182.5° INS
SOG 5.8kn
POSN INS 35°23.192' N 139°42.137' E
Offset
WGS84
TM Reset off
MENU
Route Information
Route : JPTYO-AP01C-oA1..
Plan Speed : 7.2 kn
Plan Course : 181.0°
XTD LIM: 60.0/60.0m
XTD : -3.2 m
Steering Mode : TC
TC : GoAW Appr. Enabled
To WPT : 66
DIST to WOP: 0.19 NM
Time to Go : 0: 1'59"
Turn RAD : 0.12 NM
ROT : -000.6°/min
Next WPT : 67
Next Course : 180.8°
SFT Info(1/1)
SFT 3240
Close
BRG 175.6°T
RNG 1.870 NM
COG 176.6°T
SOG 12.69 kn
CPA 0.114 NM
TCPA -16:07
BCR 0.568 NM
BCT -10:56
Reliability 100
Std.Src X
Srcs A,X,S,SR1,SR2
Status Normal
MMSI 431000705
Name SATSUKI MARU
Class Medium sized ship (80%)
Risk Lv. Safe (0.00)
Bumper missing
Fake Accuracy ***
Confirm. flag false
Plan : 7.2 kn
HDG : 182.8°
SOG : 5.8 kn
Next WPT : 180.8°
Wind : 033.6°
13.4 kn
Steering limit
182.8° Primary
ROT -001.3
DTC Status
AP WorkingStatus APU
SP WorkingStatus APU
DP Track Status Tracking Off
DP WPT Status Calculating
Flap Rudder Angle
Check ETA
WPT : 66
Distance : 0.24NM
Plan : 08:00 26 Feb 2022
Actual : 08:01 26 Feb 2022
To Localtime
Off Plan : 00:00
SPD Calculation
Suggested SPD
Overlay / NAV Tools
TT/AIS
TT OFF
AIS OFF
Vector 3min T.GND
CPA/TCPA 0.3NM 15min
AIS CPA AUTO ACT FILT
Close
MSG
Manual Update
Mini Conn -ing
EODD
DPS CTRL
ARS ON
Chart INFO
DISP
Log
Day
60
MOB
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Results of demonstration voyages

1. Westbound (26-27th Feb. 2022)
Port of Tokyo → Port of Tsu-Matsusaka off

Distance: 207.5NM (384.3KM)
Sailing time: 20h10m
Hours of autonomous operation: 19h39m
Ave. Speed: 10.3kt
Actions for collision avoidance: 107 times
* Number of avoiding ships were not countable

Percentage of autonomous operation

97.4%

2. Eastbound (28thFeb.-1st Mar. 2022)
Port of Tsu-Matsusaka off → Port of Tokyo

Distance: 216.4NM (400.8KM)
Sailing time: 19h38m
Hours of autonomous operation: 19h34m
Ave. Speed: 11.0kt
Actions for collision avoidance: 34 times
* Number of avoiding ships were not countable

Percentage of autonomous operation

99.7%

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Summary

- With the support of the Nippon Foundation, the NYK Group is working on the Designing the Future of Fully Autonomous Ship Project (DFFAS Project), which aims to develop and demonstrate an autonomous ship navigation system, with the cooperation of more than 60 partners in Japan and overseas.

- During the demonstration voyage in February 2022, we successfully conducted the first in the world to conduct long-distance voyages in congested areas with unmanned ship operations.

- In the development of the system, we are using MIL (Model-In-the-Loop) and HIL (Hardware-In-the-Loop) for verification & validation of the system to build system quality and improve the productivity of the development process.

- We are convinced that the various insights gained through this development process and the engineering methods introduced, such as model-based design and model-based development, are very important that the maritime industry should utilize them for tackling further complex systems.

Source: DFFAS CONSORTIUM

DFFAS
Designing the Future of Full Autonomous Ship

Thank you for your listening.

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